



TARDEC Collaboration – Energy Storage



TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

**Sonya Zanardelli, James Mainero, Dr. Laurence Toomey, John Zwally,
Ted Olszanski, & David Skalny**

Energy Storage Team

sonya.zanardelli@us.army.mil 586-282-5503

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Energy Storage Goals

- Develop **safe and cost** effective energy storage systems
- Reduce **battery weight & volume burden** (Increase Energy & Power Density)
- Reduce logistics and fuel burdens
- Extend **calendar and cycle life**
- Enhance performance and increase operating time (silent watch, etc)

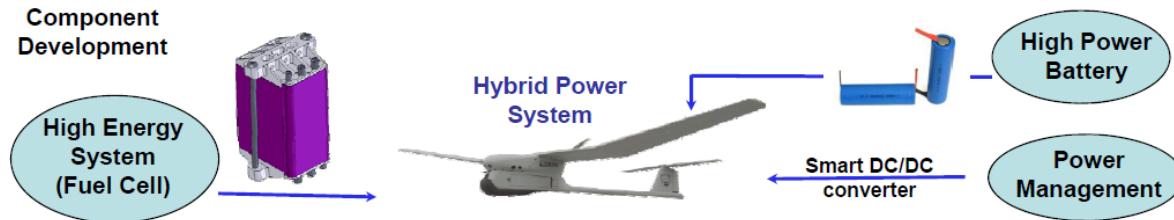
Energy Storage Mission

- **Develop** and **mature** advanced ES technologies for transfer to vehicle platforms
- Test & evaluate ES technologies for prequalification and to assess their TRL
- Identify **technology barriers** and develop technical solutions
- Provide technical support to customers, other teams and government agencies for all ES requirements
- Provide **cradle-to-grave** support for all Army ES systems



• Air Force: (mass restrictions)

- Major Applications:
 - Aircraft Emergency Power
 - Small Unmanned Aerial Vehicle (UAV)
 - Long Endurance UAV / Persistent Munitions
- Approach
 - High Energy component
 - High Power component
 - Power Management



• Navy: (volume restrictions)

- Major Applications:
 - Unmanned Underwater Vehicles (UUV)
 - Shallow Water Combat Submersible (SWCS)
 - Submarine Small Distributed Power Systems
 - Surface Ship Fuel Economy
 - Surface Ship Pulsed and High Power
- Approach
 - Modular, scalable approach to support multiple applications



• Army Applications/Drivers:

CERDEC - Soldier

- Major Applications
 - Soldier Power – *(Soldiers carry as much as 30lbs of batteries to support Mission Essential Equipment)*
 - Advanced C4ISR Systems
- Approach
 - Standard Form Factor (BB2590)
 - Fuel-Cell/Battery Hybrid Power Sources



Communications



TARDEC - Ground

- Major Applications
 - Robotics
 - Survivability
 - Weapons Systems
 - Electromagnetic Armor (EM Armor)
 - Silent Watch
 - Starting, Lighting and Ignition (SLI)
 - Hybrid Vehicle Acceleration and Regenerative Breaking
- Approach
 - Standard Form Factor (6T)
 - Ultra-capacitor/Battery Hybrid Power Sources



Hit Avoidance

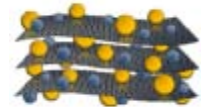


Targeting Systems



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Energy Storage Functional Breakdown



Basic Research

- Lithium plating phenomenon in Li-ion batteries
- **Study on the mechanism of thermal runaway in VRLA Batteries and Methods of Suppression**
- Study of electrode/current collector interface & safe separator for Li-ion batteries
- Development of high energy density anode materials for improved Li-ion batteries
- Alternative electrolyte for use in lithium-ion batteries (higher voltage, improved performance)

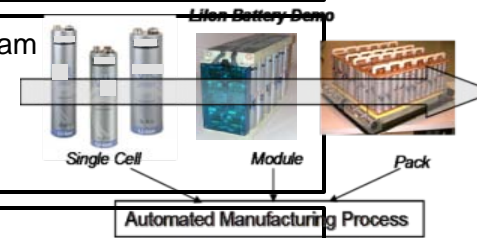
Applied / Applications Research

- Electromagnetic Armor Power Maturation
- Nickel-Zinc 6T Battery Development
- **Development of 6T battery for SLI and silent watch using lithium-iron phosphate**
- Absorbed Glass Matt lead acid battery for 24V military 4HN battery



Manufacturing

- High Power, High Energy Density Li-Ion Battery Manufacturing Program
- **Lithium-Ion Battery Pack Manufacturing**
- Advanced battery material scale-up facility



Battery Management / Safety

- **In-House BMS evaluation for PM HBCT & new laboratory**
- Universal BMS using novel algorithms for battery health
- Ballistic and abuse tolerance studies on cells, module and packs
- Development of advanced diagnostic tools for cycled cells



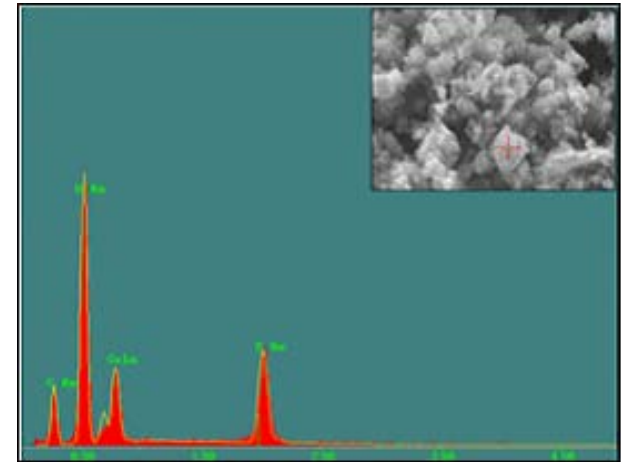
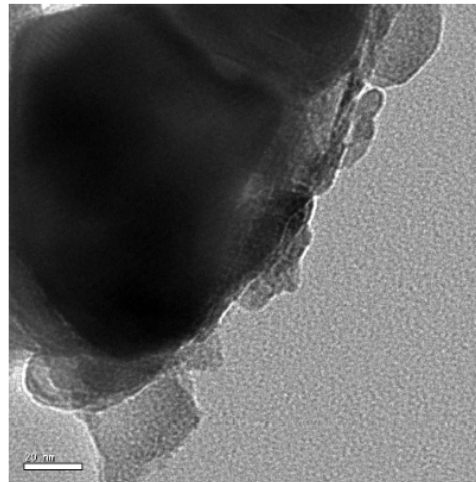
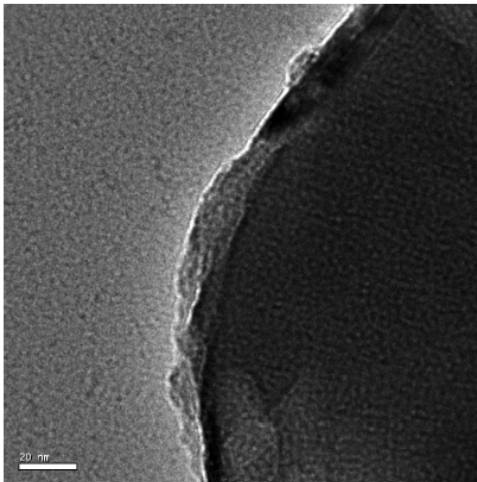
Alternative Systems

- Hybrid Power Module
- Lithium-Titanate Hybrid Vehicle Pack Integration
- **Characterization of ultra-capacitors for SLI and high power applications**





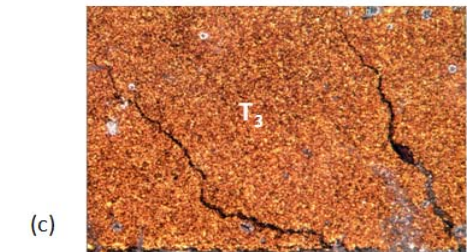
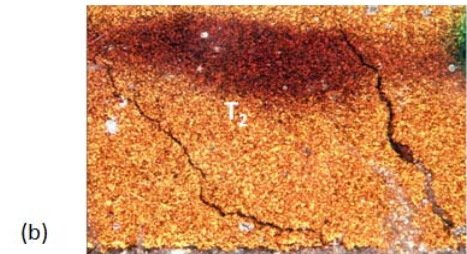
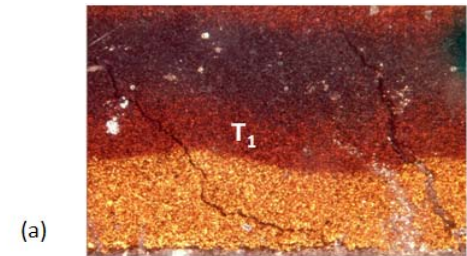
- Scale-up facility at Argonne National Laboratory (ANL).
 - Prepare scaled-up quantities of advanced materials prepared at Argonne. Initial focus is on high energy cathode materials and advanced electrolyte/electrolyte additives.
 - Process design and engineering for scale-up
 - Bulk materials production for evaluation (e.g., 1-100 kg batches or continuous)
 - Deliveries include materials to Army Labs and to battery vendors for evaluation
- Enhancing Argonne's battery post-test laboratory capabilities.
 - Develop “closed loop” feedback into materials development programs at ANL.
- Both will be user facilities.



- Research is being carried out to improve energy density by developing advanced high voltage cathode materials.
 - 2 Phase I Small Business Innovative Research (SBIR) projects
- **Project #1:**
 - Core shell structured cathode material: shell coating to enhance stability at high voltage (to 5V)
- **Project #2:**
 - Develop/optimize high voltage, high capacity cathode materials.
 - Phospho-olivine LiMPO_4 ($M = \text{Mn, Co, \& Ni}$) with high voltage electrolytes
 - Particle size, doping and carbon coating

TARDEC and Industry have an ongoing project studying lithium plating in lithium ion batteries

- Lithium plating results in loss of capacity and eventually shorts between battery electrodes
- Plating can occur when the battery is charged at a rate higher than the anode can accept charge (regenerative braking)
- Observe lithium intercalation and plating in-situ with specially designed cell
- Investigation of strategies for avoiding plating while still capturing as much energy in the battery as possible for a given set of conditions

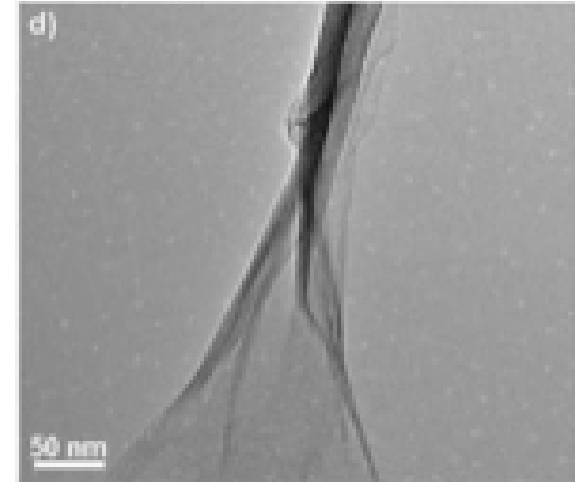


Recently TARDEC completed a Phase I Small Business Innovative Research (SBIR) project

- Silicon has the potential for significantly higher capacity than graphitic anode materials (~4200 mAh/g theoretical)
- However, silicon anode materials have suffered from short cycle life/rapid capacity loss due to expansion and contraction of the material during cycling
- SBIR project objectives:
 - Capacity: >1500 mAh/g
 - Cycle life: >500 cycles
- Portions of this effort including lab scale cell cycling and material analysis was carried out at an industry laboratory

Anode Materials

- Research study on novel carbonaceous anode materials
- First principals modeling of materials identified graphene edges as favorable for lithium intercalation
- Graphene Nano-ribbons (GNR)



Electrolytes

- Ionic Liquid Electrolytes
- High throughput examination of Li-Air Catalysts
- Graphene Electrodes
- In-Situ observation of battery Cycling
- Polymer and Solid State Electrolytes

- **Lead-Acid Battery Monitoring Systems**

- Relationships with several commercial lead-acid BMS vendors.
- CRADAs: Evaluate the commercial BMS for accuracy of vendor claims and suggestions for design improvements.
- PEO-GCS Battery Monitoring System Specification
- Stryker BMS source selection: 3 BMS were tested and evaluated against specification focused on 95% accuracy for SoC and SoH.

- **Lithium-Ion Battery Management Systems**

- Li-ion Battery OEMs produce BMS for their own battery systems.
- SBIR Advanced Battery Management Systems: Looking at developing algorithms for improved SoC, SoH, and SoL accuracy.
- BMS Laboratory capability to evaluate BMS technology readiness level independent of the battery system.

- **Battery management system & architecture design and test capability**
- **Develop in-house advanced battery test capability to assess performance and TRL of BMS technologies/systems independent of the battery pack; and standard architecture and interface for advanced ground vehicle battery packs**
- **Support battery system standardization and open pack architecture definition to support improved commonality in Army ground vehicles.**
- **Major Lab Components**
 - **Automated test control and data processing system**
 - **Hardware-in-loop (HIL) Simulator w/ Battery Models**
 - **Thermal testing via Environmental Chambers**
 - **Failure Analysis**

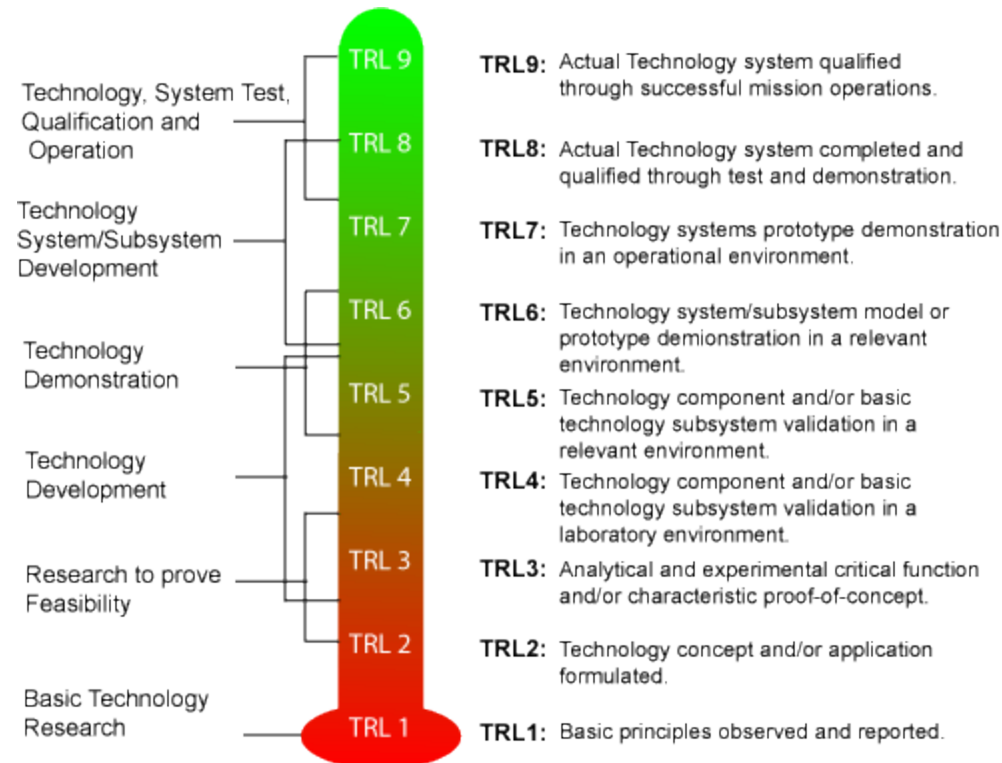
- **Purpose:** Create a single Li-ion rechargeable specification applicable to all DOD components. Results will be:
 - Standardization of test and performance requirements
 - Reducing test duplication with in DOD
 - Cost benefits include a decrease in qualification testing as well as potential replacement of multiple current chemistries with standardized Li-ion systems.
- **Participants:** Under the auspices of the Power Sources Technical Working Group (PSTWG).
 - US ARMY TARDEC
 - US Army CERDEC
 - NAVAIR
 - NAVSEA
 - Air Force
 - Marines
 - Defense Logistics Agency
- **Status:** The specification outline is created and merging of two existing specifications is complete.
- **Expected Completion:** Approximately 1 year to complete adding other services requirements and obtain services and vendor consensus.



- TRL Certification process developed for Energy Storage Systems (ESS's)
- Process provides both Government & Industry with a standard to make quantifiable measurements and evaluations of technical maturity
- ESS Process is a detailed set of requirements / tests for each of the TRL levels for specific ESS technologies tailored to the specific chemistry

• Tests include:

- BMS checkout
- Rate characterization
- Charge retention / stand
- Altitude
- Vibration
- Impact
- Short circuit
- Extreme temperature
- Overcharge / thermal runaway



Characteristic:	Units	Pack 6T Size
Nominal Voltage	V	12.0
Capacity	Ah	127.0
Total Installed Energy	Wh	1524.0
Cell Mass	kg	40.0
Cell Volume	L	13.9
Cold Crank Amps (30sec, -18°C)	A	1100
Energy Density	Wh/L	109.6
Estimated Specific Energy	Wh/kg	38.1
Battery Height	mm	209.0
Battery Width	mm	265.0
Battery Depth	mm	253.0

Approximate cost for 6T Lead Acid battery: \$250-300/battery



- USMC intention is to develop “drop-in” replacement for NATO 6T batteries
- Initial purchase of 4 batteries with option to purchase a maximum of 2000 batteries.
- **Solicitation specifies two types of batteries: High Energy and High Power**
- **Requirements:**
 - Both types: same dimensions and design as NATO 6T format
 - Key performance characteristics:

	High Energy IBS (HEIBS)	High Power IBS (HPIBS)
Voltage	12V	12V
Capacity	160 Ah	60 Ah
Cold Cranking Amps (30 sec, -19°C, >7.2V)	900A	2000A
Cold Cranking Amps (30 sec, -40°C, >7.2V)	400A	1000A

- **A 28V 6T size Li-ion Battery provides greatest flexibility:**
 - A single 6T size Li-ion battery could in replace 2- 6T size lead acid batteries
 - Reduction of logistical footprint and minimize costs penalty
 - Initial Li-ion batteries are going to cost ~\$15k to \$20k each (~\$0.20/Wh L.A. to >\$5-6/Wh for Li-ion)
 - Silent watch kit: Single 28V 6T Li-ion units could be added in parallel for Silent watch capability.
 - More cost effective/efficient module size if we were to develop a hybrid system based on this modular design.
 - Would require a 12V supply for most applications
 - Providing a 12V is a concern in the current configuration (tapping into a single battery within a string)
- **Recommendation would be to develop a specification similar to the anticipated characteristics estimated for the 28V prismatic cell 6T size Li-ion battery**
 - 25.2V nominal, >90Ah battery in a 6T size format

- **Army has a diversified energy storage portfolio supporting a wide-range of customers**
- **Army has and is actively seeking collaboration with other Government Agencies, and Commercial & Military OEM's**
- **Army has projects supporting several different functional areas in Energy Storage including: basic research, applied research & applications, manufacturing, battery management & safety, and alternative systems**
- **Army labs currently perform a wide variety of testing activities and has an established program for technology maturation and technology readiness level verification**
- **Army is actively involved in the development of battery standards and standard vehicle battery products**



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